Surface-Mounted Lights on Roadways for Guidance

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●THE MATERIAL presented in this paper is an outgrowth of developments that have been made in lighting for airports. Recently the Institute of Transportation and Traffic Engineering of the University of California had a research project sponsored by the Bureau of Research and Development of the Federal Aviation Agency to consider the problems of airport runway capacity. In connection with this study, it was necessary to develop a means of delineating an airport runway and a high speed exit taxiway for all weather conditions including daytime, nighttime, and adverse weather. The lighting units that were developed for the FAA have been installed at the McClellan Air Force Base at Sacramento, California and at the San Francisco International Airport. The system may have potential applications to roadways since the basic visual problem of the motor vehicle driver and the pilot is the same.

There are many aspects to the visual perception problem of the motorist. These involve the contrast between adjacent brightness patches, the acuity required to resolve fine detail coupled with the dynamic characteristics of motion, plus a sense of orientation in the spatial field. An analysis reveals that the major information required by a driver is contained in the contour lines that outline the basic elements of the scene. Insofar as the roadway itself is concerned, the basic elements are determined by lineal lines that define the edges of the roadway, the intersections and the turnoffs, the lane lines and the center lines. These basic components are further supplemented by other fine points of perception such as surface detail, color of elements, glossiness of surfaces, and familiar shapes of objects in the field of view. But probably 90 percent or more of the visual information is conveyed to the driver by means of the lineal pattern forming the outline of the basic elements. This idea of contour perception has been used as the basis for establishing a lighting system, using a large number of small light sources spaced on short center distances (approaching the minimum angle of resolution) which will then provide a continuous bright line. The principle of contour perception is recognized in the work of all artists wherein the outline of the scene is drawn first. The details of the texture, shading, color and variations of brightness are used later to bring out the more subtle attributes of the picture. The same principle is used by cartoonists who employ a few simple strokes to convey the basic features of people in caricatures. Similarly, mechanical drawing techniques use the outlines of the parts to provide all of the information needed by an engineer or a technician.

Figure 1 shows the principle of contour perception applied to the runway of an airport. The turnoff for an exit taxiway is shown from a long distance away as well as from a closer position. In either case the scene continues to change from distant to close viewing and provides a continuous supply of information regarding the approaching turnoff. It is desirable to have the lineal effect continuous if the information is to be automatically interpreted.

The Development of a System for Contour Perception

The foregoing has indicated the desirability of a lighting system to develop continuous contours of light along borders and centerlines of roadways. Figure 2 shows a pattern of lights used to define the runway and exit taxiway at McClellan Air Force Base. The edge lights are on relatively large spacings of 50 ft, except in the region of the turnoff where they are spaced at 33 ft. The centerline of the runway has lights on 20-ft centers, whereas the centerline through the turnoff has lights on 10-ft centers. Spacings from 50 to 10 are illustrated in the photograph to show the relative effect of close versus wide spacing to provide the lineal pattern.

The line used to form the contour should have a high contrast with its background.

In order to build up such a high contrast, it is desirable to use direct light sources rather than reflected light. Filament light sources are a logical choice for this design due to their high brightness and simple electric circuitry. If the sources have high brightness, they can be seen against a background which is also relatively high in brightness as in daytime fog. Small filament lamps in the order of 3, 5, or 15 watts are suitable for this purpose since they operate at about the same brightness as higher wattage lamps of greater candle power. The brightness is the flux per unit area per unit solid angle and this is a characteristic of the filament temperature rather than the size. Small light sources can be used to build up a pattern of lights and the light sources can be arranged on close centers so that at near grazing angles (at which they are viewed by a driver), the filament intensities will add together to form a much higher apparent brightness than each single source alone. This effect can be visualized by looking at a ladder lying on the ground ahead. The distance between individual rungs appears foreshortened as the eye position is lowered and the rungs become stacked one on top of the other until the surface looks solid. If filaments are substituted for the rungs of the ladder, the brightness build-up effect can be visualized. This system has several advantages: small sources can be used so that surface mounted fixtures can be designed to protect the sources from wheel impact and yet the complete assembly need not protrude more than a fraction of an inch above the roadway surface. Thus, the fixtures can be rolled over without damage by vehicles. They can be surface mounted on the roadway at nominal installation costs. Furthermore, when small sources are used, there is very little flash-by effect; there is very little flicker in the peripheral field for the units along the edges of the roadway and the glare from each source is negligible. The pattern of lights in depth at constant spacing provides a reliable indicator for speed of travel and develops a good means of judging distances both on the straight-away and when approaching curves, turnoffs, or other important junctions in the roadway.

The lighting unit that was developed to meet the above requirements is a small flat circular disc-shaped fixture that uses either a 3-, 4- or 15-watt 12-volt automotive type light bulb as shown in Figure 3. The bulb selected for this fixture is a tubular shaped bulb used principally in foreign automobiles and is manufactured by a number of European companies. The 3-watt size is quite adequate for roadway use and is preferable because

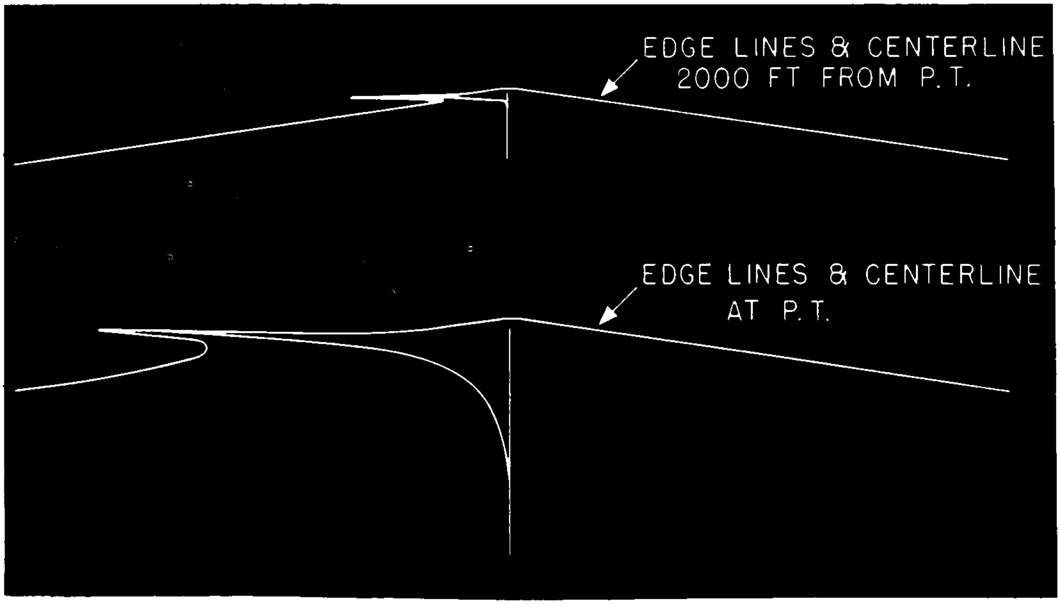
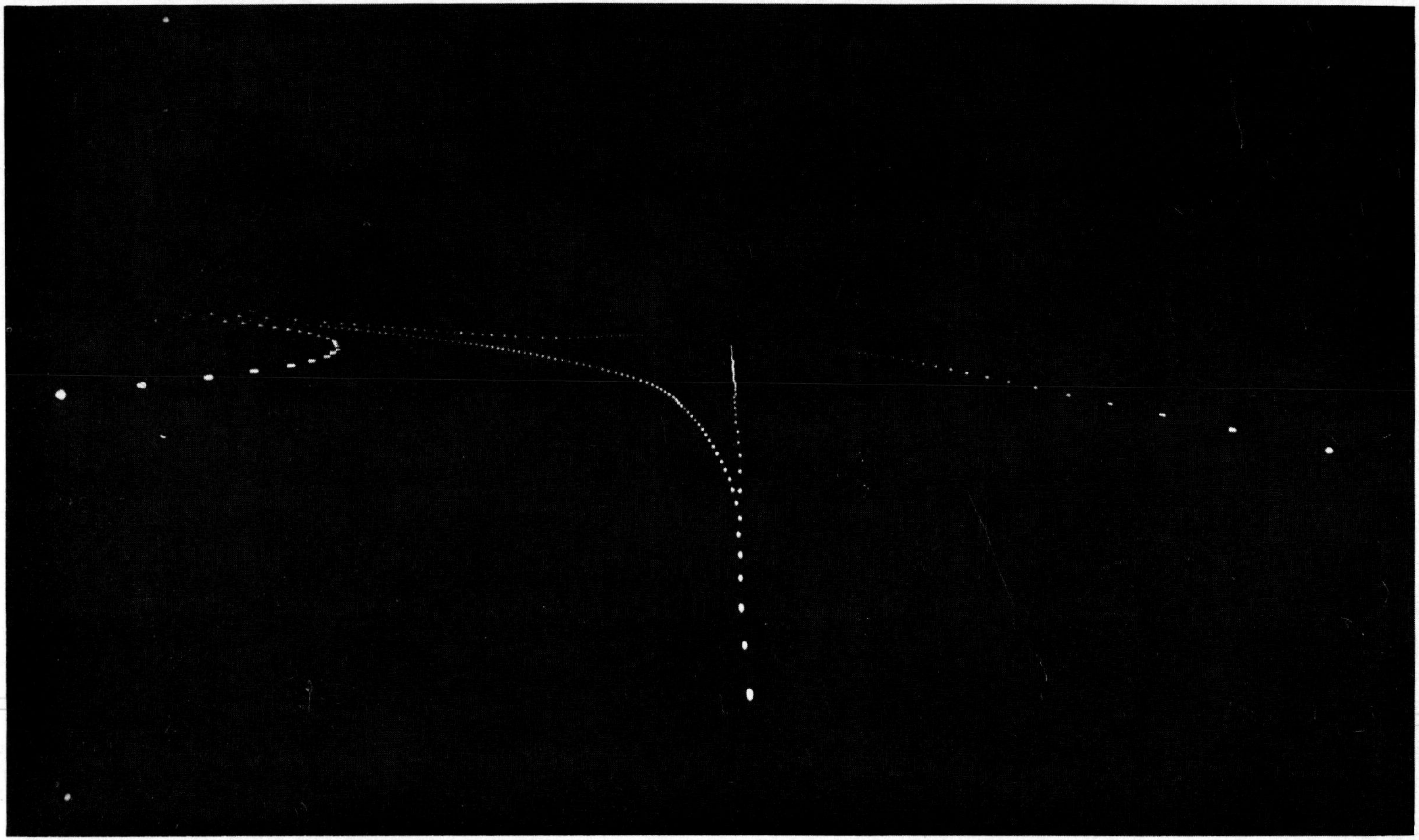


Figure 1. Edge and center contour lines.



Lighting: Edge plus Centerline
Location of Camera: At point of turn
Height of Camera: 13 feet
Bulb: (Edge: 5 watts; 14 volts
(Centerline: 3 watts; 12 volts

Spacing of Lights (feet)				
Edge		Centerline		Across
Runway	Taxiway	Runway	Taxiway	Entrance
50	33	20	10	--

Figure 2.

of its small cross-section. The particular lamp shown in Figure 3 is 7.5 mm in diameter and can be mounted in a unit having a total height above the roadway of only ½ in. The fixture can be run over by automobiles without damage to either the fixture or the car. A noticeable roughness is felt in most cars, particularly at slow speeds. At high speeds the roughness is still apparent but is not intolerable and does not seem to constitute a driving hazard.

The present design is experimental but a number of design features were considered in its development, such as access for bulb maintenance. The top is open so that the bulb can be snapped in or out by hand or with simple tools. Drainage is not a problem since the units are slightly above the roadway surface. The collection of dirt and debris in the throat has not been a problem so far since tire action provides a certain amount of self cleaning. The units have not been tested in conjunction with snow plows or other snow removal equipment. Problems may arise in areas where snow and ice are present, but the heat of the bulb itself is probably sufficient to melt snow or ice in the immediate vicinity of the bulb and in the throat section.

The low operating voltage was selected because of the availability of the low wattage bulbs in the tubular shape. Low voltage has other advantages: It is safe, and ground-lay or surface-lay wires can be used without conduits. Minimum clearances can be used in the fixtures; the exposure of electrical contacts in weather is not a serious problem, and feeder lines can easily be run in from the side supplied by transformers with high voltage primary circuits.

Mounting of Light Units

Several methods of attaching units to the roadway surface are available: With heat treated drive nails; with studs explosively driven into the roadway plus machine screws

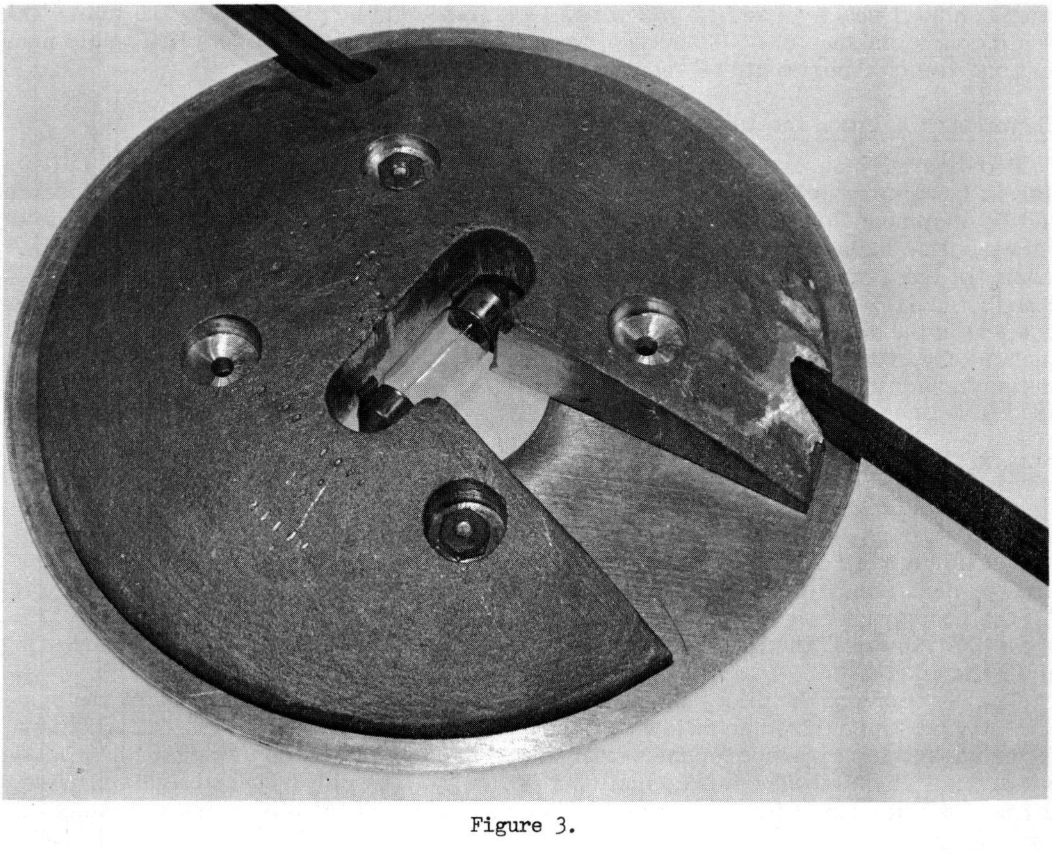


Figure 3.

to fasten the units to the studs; and, with adhesives. All three techniques have been used experimentally. It has been found advantageous to use the adhesive method for experimental purposes. A rubber-base adhesive has proved very satisfactory on both concrete and asphaltic surfaces. The particular material that has been most successful is Stabond No. T161 used with a toluene thinner. The surface must be clean and dry when the adhesive is applied. The adhesive will require several hours to set up firmly. In areas where some of the roadway use will occur prior to complete setting-up, cloth adhesive tape in addition to the bonding material was used. In a permanent installation the adhesive tape would probably not be used.

Power Supply and Service Distribution

The lighting units have been arranged in two basic systems which can be operated independently: a centerline system, and an edge lighting system. At the San Francisco Airport installation the centerline system has additional switching so that the spacing can be changed in order to evaluate its effect on the visual conditions. The supply wire for the 12-volt system was two-conductor No. 14 gage running parallel to the line of fixtures. Each fixture was connected by short pig-tail leads and clip-on connectors. A special terminal was developed to attach to the supply wire so that it was not necessary to strip and splice the wire. A brass U-shaped clip was arranged to go over the outside of the wire. A copper tack was used to pierce through the clip and the stranded wire and was riveted on the opposite side. The 12-volt supply line was connected to the high voltage feeder-line at the side of the runway by means of lateral lines for every 20 lamps. With this arrangement of wiring the voltage gradient along the lights was less than one volt between the maximum and minimum point in the system. This was adequate for uniform brightness. It was determined that a voltage drop of 2 volts along the 12-volt system would have been satisfactory, but that a 3-volt drop along the system gave noticeable brightness variations. For a 2-volt drop along the system and with the lamps on 50 ft spacings and No. 12 wire, 10 lamps could be placed along the line. This would give a distance of 500 ft in both directions from the lateral line which would mean that one transformer would be required per 1,000 ft.

Photometric Data on the Lighting Unit

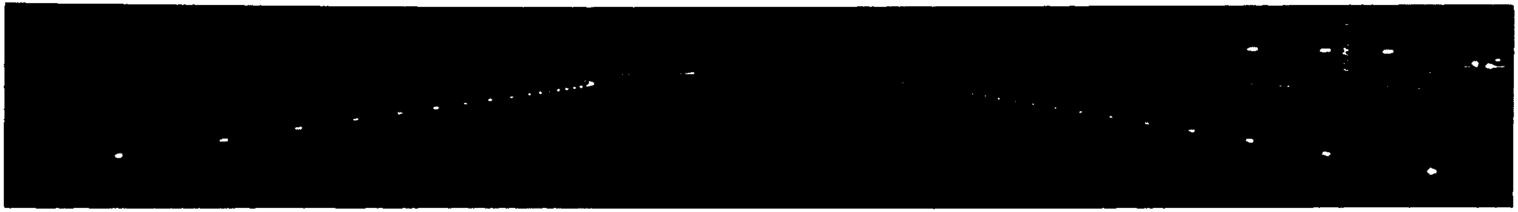
Photometric measurements have been made on the units at the University of California laboratory in Berkeley, California, at the Air Force Wright-Patterson Research and Development Center in Columbus, Ohio and at the CAA Experimental Airport at Indianapolis, Indiana. All of these reports check and indicate that the maximum intensity of the 5-watt light at rated voltage is approximately 7½ candle power and is distributed over a horizontal angle of approximately 20 deg to each side of the centerline and in the vertical direction from the surface (0 deg) up to more than 90 deg. With such a very broad distribution the units appear equal in brightness from all viewing angles including directions considerably off to the side. This permits the unit to be used to delineate curves and edges which may be in the peripheral view of the driver.

Discussion of Results

The work at McClellan Air Force Base permitted a preliminary evaluation of the effect of spacing and brightness of the edge lights and centerline lights. The spacings at McClellan Air Force Base varied from 100 ft on the edge lights down to 10 ft on the taxiway centerline. Some of the patterns of lights are shown in Figures 4, 5, and 6. All the photographs were taken from the eye position of the pilots, approximately 13 ft above the runway. The light bulbs in all of the photographs are 3 and 5 watts operating at 12 and 14 volts.

The reactions of the pilots and observers to the night guidance provided by the system may be summarized as follows: During clear weather all of the various spacings of the edge lights provided guidance that was at least good enough to permit the pilot to negotiate the high-speed turnoff without difficulty. The close-spaced lights provided the best delineation of the boundaries. However, many of the observers and pilots

At Point of Turn



700 ft Ahead of Point of Turn

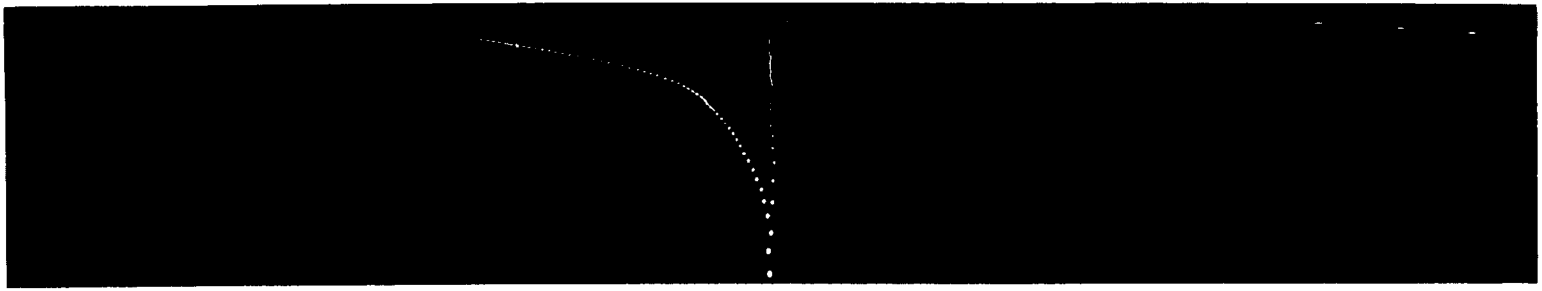
1500 ft Ahead of Point of Turn

Location of Observer: 13 ft above runway

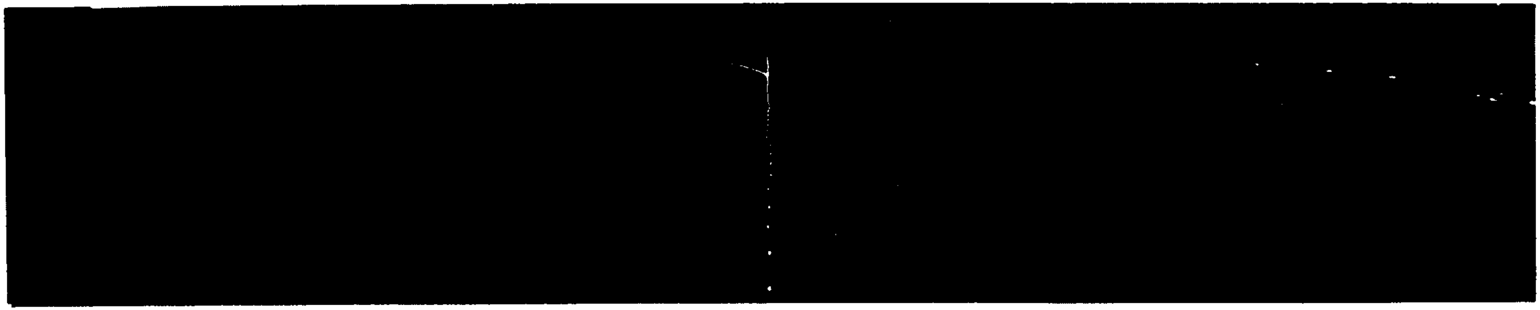
Bulb (Edge: 5W at 14V
(Centerline:-

Spacing of Lights (ft)				
Edge		Centerline		Throat
Runway	Taxiway	Runway	Taxiway	Runway
50	33	-	-	-

Figure 4. Edge lights only.



At Point of Turn



700 ft Ahead of Point of Turn

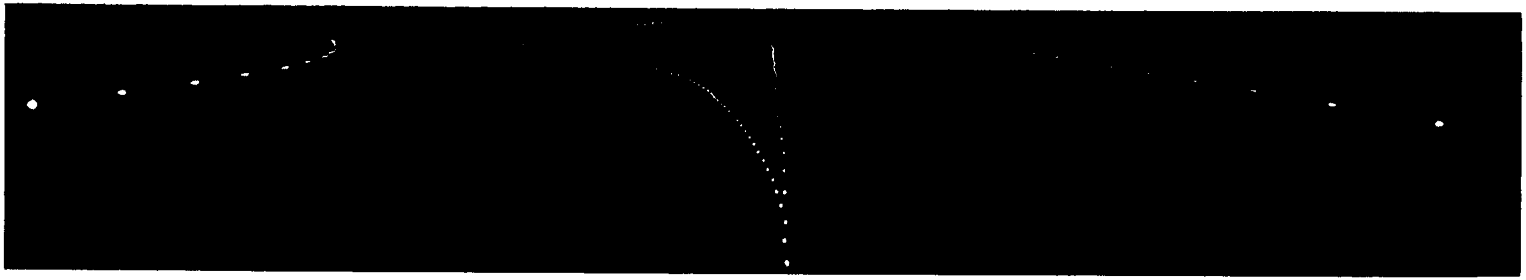
1500 ft Ahead of Point of Turn

Location of Observer: 13 ft above runway

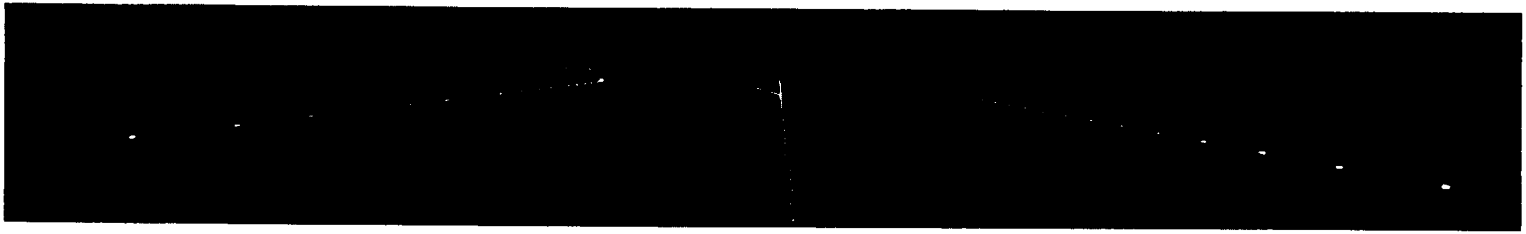
Bulb: (Edge:-
(Centerline: 3W at 12V

Spacing of Lights (ft)				
Edge		Centerline		Throat
Runway	Taxiway	Runway	Taxiway	Runway
-	-	20	10	-

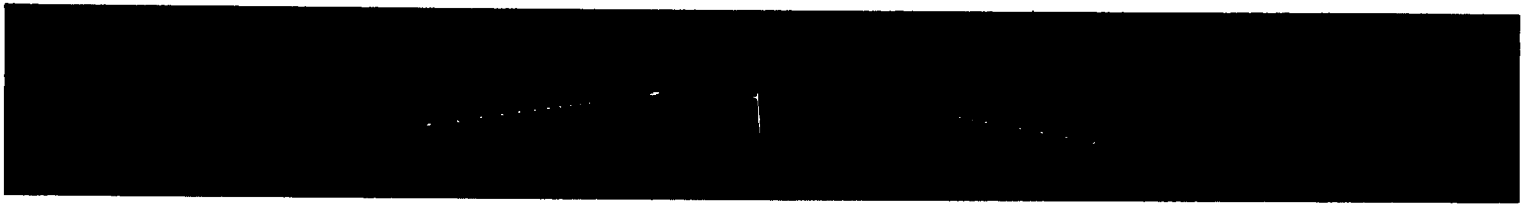
Figure 5. Centerline lights only.



At Point of Turn



700 ft Ahead of Point of Turn



1500 ft Ahead of Point of Turn

Location of Observer: 13 ft above runway
(Edge: 5W at 14V
Bulb: Centerline: 3W at 12V

Spacing of Lights (ft)				
Edge		Centerline		Throat
Runway	Taxiway	Runway	Taxiway	Runway
50	33	20	10	-

Figure 6. Centerline plus edge lights.

stated that the 100-ft spacings on the edges of the runway with closer spacings on the edges of the exit taxiway were satisfactory. Closer spacing was desirable on the far side of the exit taxiway in the region of the junction with the runway. On the basis of these preliminary reactions, the spacings of the lights along the far side of the taxiway were reduced to 3 to 5 ft apart around the nose and 5, 11, and 16½ ft along the remainder of the line extending into the turnoff area. The comments indicated that the guidance provided by the contour type pattern even with fairly wide spacing was so much better than the usual taxiway markings on 200-ft spacings that the turn-off could be made safely with the edge lights only. The point-of-turn was not well defined with edge lights only, but this did not seem to seriously affect the pilot's judgment of the turn-off during the clear weather tests.

With the centerline only the pilot and observer reactions indicated that the system gave a clear and unmistakable path to follow on the runway and clearly indicated the beginning of the turn. The point-of-turn is well defined by the tangent point where the two centerlines meet. With close spacing and the near grazing angles at which these lights are observed the brightness build-up at the point-of-turn due to the ladder effect, is quite apparent. This provides a natural high brightness region upon which the pilot or a motor vehicle operator would automatically concentrate.

In the airport studies the centerline by itself left something to be desired. The observers indicated that, while the path was completely defined, it was important to also know where the edges of the runway were. Thus it seemed that some lack of spacial orientation and uneasiness were felt with the single bright line in a large dark void. For all spacings of the centerline lights up to 100 ft and with either 3- or 5-watt light sources there were no adverse criticisms regarding the flicker or the flash-by effect. With the 5-watt centerline lights operated at 14 volts, the brightness was considered to be too high in clear weather. For normal visibility the brightness at voltages as low as 8½ volts seemed to be more pleasant and quite adequate. Under conditions of adverse weather, fog, etc., it would be desirable to go to the higher voltages.

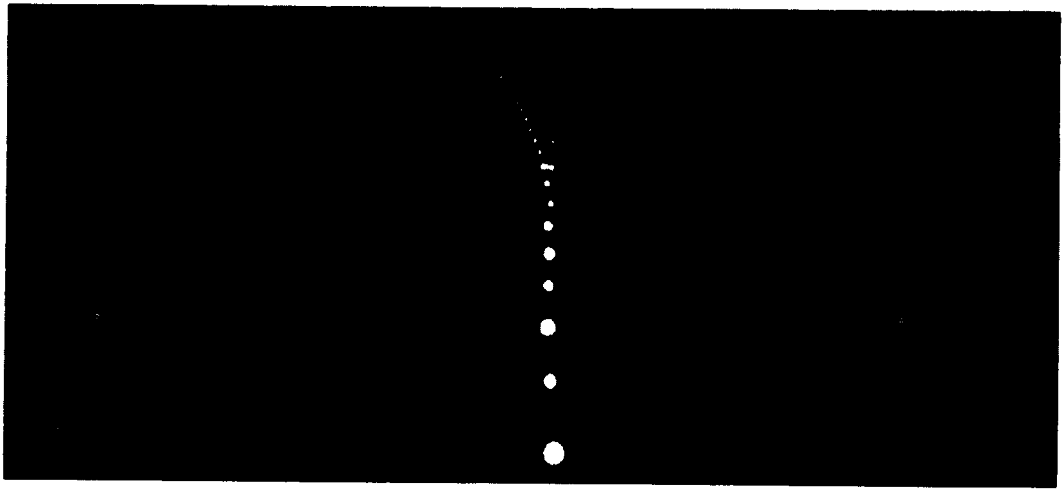
The combinations of centerline plus edge lighting gave the most favorable pilot and observer reactions. This would be expected because of the completeness of the lighting pattern that was developed. It was possible to set up many combinations of spacings and brightness to provide a guidance system using the basic concept of contour perception. The experiments did not attempt to determine the optimum arrangement of lights but were rather to establish the principles upon which a night guidance lighting system could be developed.

It was concluded that the best conditions for night guidance are obtained by drawing full lines of high contrast along the edges and along the centerline of the airport runway and to mark the turnoff point for exit taxiways with a centerline in the taxiway which departs from the runway centerline at the point-of-turn and proceeds through definite break in the edge lighting at the entrance to the turnoff. The edge lighting should develop a completely defined border at the turnoff and the turnoff centerline should extend continuously from the main runway centerline through the exit-taxiway into the turn for a substantial distance. These conclusions which were developed for the airport problem could be applied with very little modification to modern roadways.

On several occasions during the test heavy rain was encountered such that the windshield wipers for the airplanes could not keep the visual field clear. It was noted that the composite system using the centerline plus closely spaced edge lighting was considered to be the best under those adverse weather conditions. On one occasion at McClellan Air Force Base heavy fog was encountered in the early morning hours. The official visibility was reported at 0-0 which may be interpreted as less than 300 ft visual range. The centerline system with lights on 10 ft centers provided rather remarkable guidance under these conditions even though the edge lights became completely obscured. Figure 7 shows the lights in heavy fog.

Fog Chamber Studies

The field work using these lights in adverse weather indicated the desirability of further experimentation. Since fog is rather difficult to control in natural environments,



Pt of Turn Visibility: Less than 300 ft reported at the control tower
4:00 a.m. Sky - dark

3W, 12V centerline
5W, 14V edge

Figure 7. Centerline plus edge lights— heavy fog.

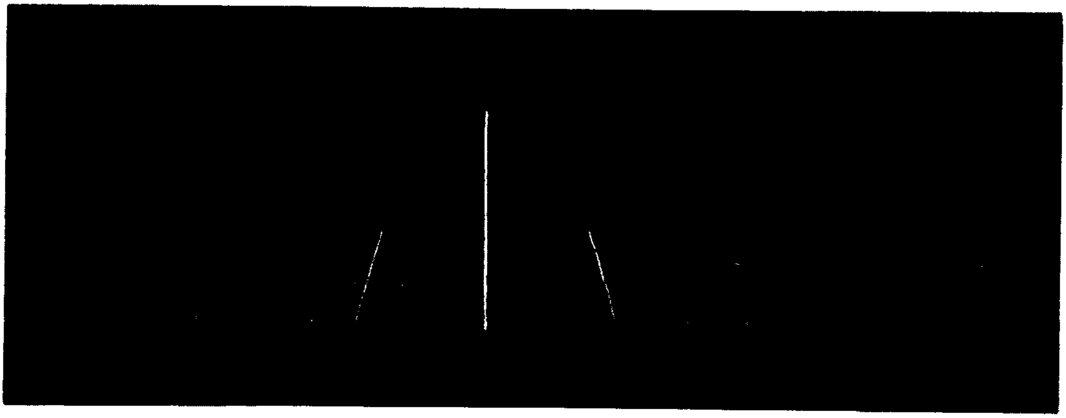


Figure 8. No fog—5 watt lights.

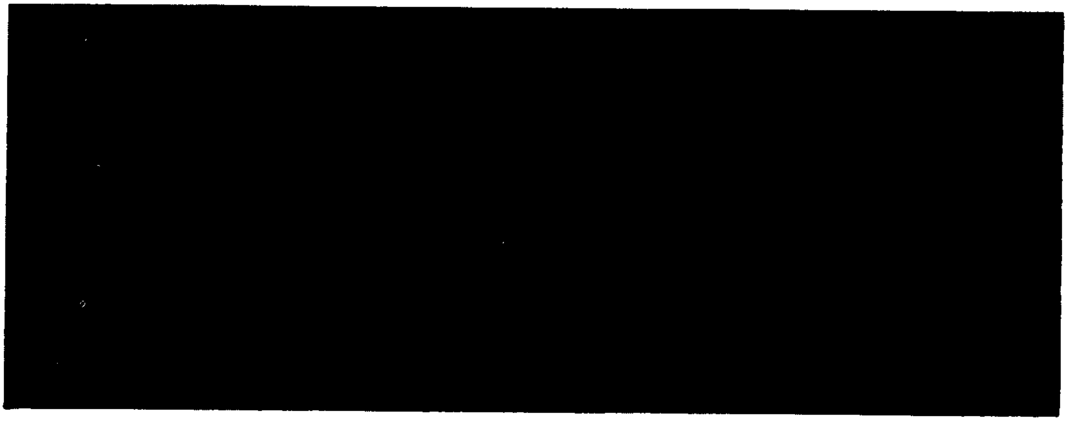


Figure 9. Heavy fog 1 percent transmission to lights at threshold - 5-watt lights.

it was decided to attempt to build an artificial fog chamber so that lighting patterns could be examined under various controlled densities of fog. A suitable chamber approximately 400 ft by 25 ft wide by 25 ft high was obtained on the Berkeley Campus of the University of California under the Edwards Field Stadium. The space was sealed off and a fog generating system installed consisting of special nozzles using air and water under pressure. The details of the fog chamber installation will be described in a later report. Controllable fogs were generated with almost any required density. The lighting pattern to be set up for the San Francisco Airport were set up in the fog chamber as shown in Figures 8 and 9. Various fog densities were used with transmittances of 1 to 100 percent in a 200-ft baseline. The fog chamber studies were used to develop the experimental spacings and patterns of lights to be used operationally at the San Francisco Airport. The San Francisco installation is now largely complete and is in the process of flight evaluation. The spacings at the San Francisco Airport have been decreased to a minimum of 2½ ft between lighting units at the threshold or touch down end of the runway. Provision is made for 15-, 10-, 5- and 3-watt bulb sizes so that the effect of the brightness build-up on close spacings can be studied in low visibility weather. The evaluations are not complete but the preliminary work indicates that the lighting pattern will assist in reducing the weather minimums that are now permitted for the landing of aircraft. If the visual aspects of the pattern prove to be as useful as the preliminary studies indicate, the remaining research that will be required to work out the mounting technique, proper electrical connections, elimination of bulb damage, two-way viewing, and a study of snow removel and dirt collection problems will continue. All of these are important but are secondary to the primary problem of establishing proper visual guidance.

These initial studies suggest that a lineal pattern of lights surface mounted on the pavement may have considerable application possibilities in the highway field. The lights can provide good lineal guidance in almost any weather which is one of the most essential factors in motor vehicle operation.

REFERENCE

1. Horonjeff, Finch, Ahlborn and Belmont, "Design and Location of Exit Taxiways." Institute of Transportation and Traffic Engineering, University of California, Berkeley, August (1958).